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RATIONAL METHOD OF DEVELOPING A SHALLOW GROUND-WATER SUPPLY[1]

BY W. D. P. WARREN[2]

One of the most interesting and perplexing problems which an engineer is called upon to solve is that of developing a supply of water from shallow-ground wells. To the public, the big impounding reservoir, with a "visible supply of water," is a real engineering accomplishment; however, at times, it may be exactly otherwise. The author has given some study to the development of both impounded and well supplies and fully appreciates the necessity of the impounding reservoir under certain conditions. The plan of developing water from wells is an extremely old one, and yet one on which the best technical advice should be obtained before final plans for developing an impounding reservoir are adopted.

A few years ago the author was called upon by the officials of Witt, Illinois, to assist them in developing a supply of water, and the difficulties encountered in the development of this supply led to a somewhat more extended study of well supplies than might otherwise have been thought necessary. In the development of the supply at Witt, valuable support was given by the mayor, Dr. Charles Lockhart, who, being a professional man, realized the value of professional services in this matter and gave every assistance possible.

A typical problem. Witt is a city of 3,000 population, and inasmuch as the conditions encountered there are more or less typical, it will serve to illustrate the method of developing water from shallow-ground wells, to which it is desired to call attention.

The first information given the author at Witt was that the City Council as a whole wished a visible supply of water, also that there was no chance for a well supply, as both mines in that vicinity were dry, and further that the only wells near the city were shallow and showed no promise of an adequate quantity. Further investigation disclosed the fact that the engineers for the State Water Survey had been over the ground several years previously and had made a brief although valuable report. Following is an extract from the letter of transmittal of June 4, 1913, by Paul Hansen, engineer; attention is called to the fact that in this letter he pointed a way to the proper solution.

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[1] Read before the Illinois Section, March 24, 1920. Discussions are invited and should be sent to the Editor.

[2] Miller, Holbrook, Warren & Company, Decatur, Ill.

> At present there are no available data which would point to a successful water supply, but it would seem worth while to prospect by means of test wells, especially toward the notheastward, at a distance of several miles, where the city of Nokomis has been very successful in securing an abundant supply of water from wells penetrating sand and gravel in the drift at a depth of about 40 feet.

Quite contrary to the advice of the State Water Survey, a number of the officials determined to undertake the development of an impounding reservoir, the thought being that a well supply was too uncertain. Under these circumstances the investigation of a surface supply was begun.

Impounded supply. Surveys were made on a number of sites considered feasible, but as the territory about Witt is comparatively flat or rolling, no site was found nearer than 4½ miles from the city. The drainage area here was considered sufficient, and this project appeared feasible, although a filter plant would have been required for the treatment of the water to render it suitable for domestic use. The surveys and estimates on the various sites were shown in a report covering the investigations for the city.

The estimated cost of the supply from the impounding reservoir, delivered to the city, and not including distribution system, was about $125,000. This amount was greatly in excess of any figures the officials had in mind for such a supply, and it was no doubt due in a measure to this fact that they were led to adopt the recommendations contained in the report that a full study be made of a possible well supply before deciding to adopt any plan for an impounding reservoir.

Investigation of well supply. In undertaking to develop a well supply the author was limited in the beginning by a resolution of the city council to the effect that not to exceed six wells should be drilled. Several days spent on the ground disclosed the information that a mine in the south part of the city was dry, also that a mine about one mile north of the city was dry, and that the closest known well proposition was at Nokomis, about 4½ miles northeast of Witt. A visit was therefore made to Nokomis and valuable information secured from the officials in charge of the plant at that place. The Nokomis supply is from six 6-inch wells about 40 feet deep, the wells being driven into the drift and passing through 20 feet of soil and clay and 25 feet of coarse water-bearing sand and gravel. The gravel appeared to be of a grey or bluish color with little silt or clay in it, being of similar color and character to the material from which the supply at Bloomington, Illinois, is secured. At this time it was considered that the supply at Nokomis, being in a wide flat valley, might be found further down in a general southwesterly direction toward Witt, but east of the closest point to the city limits by about 3000 feet. This theory that the gravel deposit might continue down the valley was borne out in a way by information that in sinking a new mine southwest of Nokomis, considerable water had been ecountered and it had been found necessary to change the location of the proposed mine to a point somewhat further east from the general lines of the valley. A conference was held with M. C. Sjoblom, acting chief engineer of the Department of Public Health at that time, and much credit is due him for his excellent advice in this matter. The statement of Mr. Sjoblom was to the effect that if it was necessary to go 4½ miles for a supply from an impounding reservoir and then treat the supply, it would be much more practicable to develop a well supply, even if necessary to go somewhat beyond the 4½ mile limit. In other words a real tangible starting point was established. Inasmuch as the supply at Nokomis had been very thoroughly tested over a period of years and was known to be adequate, it was therefore seen that Witt could at once get a well supply from Nokomis, only 4½ miles distant, and thereby effect a very substantial saving over the method of an impounding reservoir.

Drilling. The location chosen for putting down hole 1 was in about the center of the valley, 2 miles southwest of Nokomis and roughly in line with the Nokomis wells and the mine test hole 1 mile southwest of Nokomis, above referred to. At a depth of 20 feet water-bearing sand and gravel of excellent quality were encountered, 10 feet in depth, giving a total depth of 30 feet for the well. The well driller called attention to the ease with which the well casing and drill seemed to go through this gravel deposit and stated that the flow of the water appeared to be extremely "free." This gravel was of a greyish or bluish color. Hole 1 indicated an adequate supply of water for Witt at a distance of only about 2 miles from the city. However, it was thought that the deposit would probably be found down the valley and closer to the city limits.

In selecting a site for hole 2, it was decided to choose a point on the west edge of the valley, and in so doing, the hole was located within a short distance of a little branch entering the valley. As a result considerable silt and clay were found in the sand, probably due to action of the currents caused by this small branch entering the valley proper. Furthermore, the sand did not run as coarse as in hole 1 and was of a yellowish color. It was concluded that this hole was on the western edge of the deposit, for it was very similar to holes put down about that time at the mine 1 mile south of Nokomis, which was known to be east of the main gravel deposit.

Hole 3 was about 200 feet east of hole 2, but showed much fine sand, also holes 4 and 5, which were about 500 feet north of holes 2 and 3, showed more or less fine sand. However, hole 5 showed better sand and as it lay more nearly in the center of the valley it was concluded that further drilling would locate the coarse material where the flow through the gravel would be more "free."

Considerable pressure was brought to bear at this time to induce the city officials to stop such "useless waste of money" in drilling holes out in the country and to either put down some holes in Witt where the city owned several vacant lots, or abandon the drilling entirely. This attitude at Witt was anticipated and met only by a careful statement of the methods being followed in the development of this supply. It is proposed in this article to refer to the method of developing the supply from shallow wells as the rational method, for, as in the case of sewer design by the rational method, opportunity is given for exercise of judgment and experience, as well as for the application of fundamental engineering principles.

Rational method. In the study of the problem at Witt careful search was made of available works on water supply from wells, and only a very few authors were found who gave a clear and reasonable method of procedure for the development of a shallow-ground water supply.

Hubbard and Kiersted in their book, "Water Works Management and Maintenance" have set down in simple language the following fundamental considerations which govern:

No more water can be continuously taken out of the ground than goes into it.

The yield of the ground-water is dependent upon the character and extent of the catchment area and depth of the saturated water-bearing material.

The velocity of flow of ground-water depends upon the character of material through which it must pass in gravitating from a higher to a lower level.

The stability of the ground-water supply depends upon the three considerations above stated as well as upon available ground storage at the point selected for developing the water-supply.

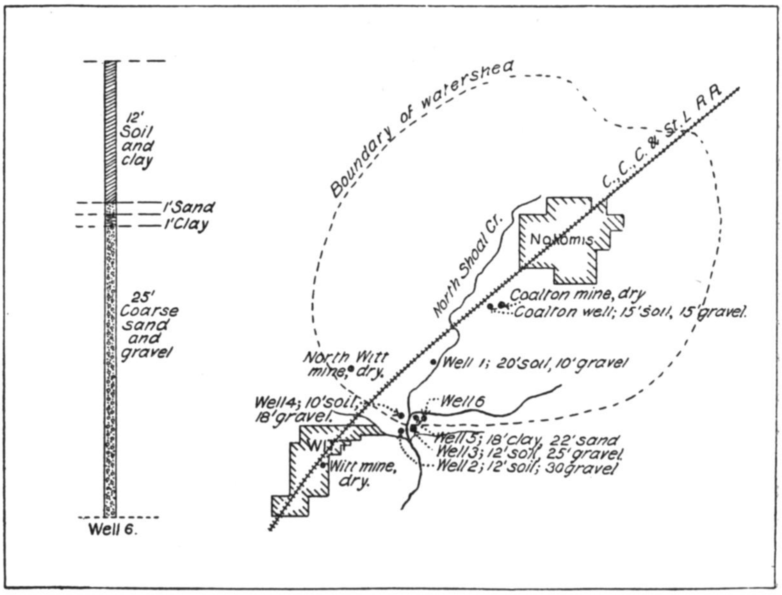
12' Soil and clay
1' Sand
1' Clay
25' Coarse sand and gravel
Well 6.
Boundary of watershed
C., C., C. & St. L. R. R.
North Shoal Cr.
Nokomis
Coalton mine, dry
Coalton well; 15' soil, 15' gravel.
North Witt mine, dry.
Well 1; 20' soil, 10' gravel
Well 4; 10' soil, 18' gravel.
Well 6
Well 5; 18' clay, 22' sand
Well 3; 12' soil, 25' gravel.
Well 2; 12' soil; 30 gravel
Witt
Witt mine, dry.

FIG. 1. SHALLOW GROUND-WATER DEVELOPMENT AT WITT

From a study of figure 1 it is seen that the area of the watershed northeast of Witt is 20 square miles, a sufficient catchment area from which to secure water for a much larger city. Evidently, then, we have a much greater promise of an adequate supply from this valley than from any point nearer the city with a less catchment area, assuming that we expect to develop a shallow-ground supply.

Furthermore we see that the yield is dependent upon the depth of the saturated water-bearing material. With the large number of holes put down on this area the average depth of saturated water-bearing material was determined as approximately 20 feet. The velocity of flow is governed in a large measure by the size of the sand and gravel particles, the coarse material permitting the water to flow much more freely. As stated above, the material ranged in size from fine sand to particles of gravel 1 inch in size, the samples taken from the different holes giving positive information on this point.

The available ground storage in this case was determined by learning the length, width, and depth of the saturated water-bearing material, computing the storage in gallons on the basis of one-third the volume of sand being void space, and also on the basis that one-third the average annual rainfall, or 12 inches, was the available under-ground run-off. "Water Work Management and Maintenance" by Hubbard and Kiersted gives additional information on this point.

It is thus seen that the elements of uncertainty as to the well supply have disappeared, that we have definitely determined the watershed area, the capacity of the underground storage basin, the size and quality of sand or gravel water-bearing deposit and the rate at which it may be expected that water will flow through the deposit to the wells.

It is interesting to note here that engineers too frequently fail to cite their authority for engineering practice which they propose. The average water-works official is very slow to dispute an engineering principle laid down by an authority on the subject, just as he is slow to argue when his attorney cites some legal principle and presents his Supreme Court decisions or his other proper authorities.

Testing supply. A most important feature in the development of a well supply of water, as considered by some authorities, is a long-continued pumping test, covering a period of several weeks or several months. While a sparkling stream delivered from a well for several weeks will look quite convincing to many officials, and in fact may prove of some value in a study of the supply, it is probably more often misleading than valuable. As an illustration, assume we desire to test a well by pumping at a rate of 1,000,000 gallons per day for 30 days, also that the deposit from which the supply is furnished has a storage capacity of 60,000,000 gallons, with a somewhat limited watershed area. It is readily seen that the well might be pumped the full 30 days and appear to be strong at the end of this period, when as a matter of fact an additional 30 days pumping would exhaust the supply. It is readily apparent, therefore, that a pumping test alone cannot be conclusive.

The pumping tests at Witt were carried on over a period of about two weeks. It was frankly stated to the officials at the time, that a pumping test over any considerable number of days was not necessary in view of the previous knowledge of the fundamental elements which controlled the supply. During the time tests were being made, G. C. Habermeyer, acting chief engineer of the State Water Survey, was present and the following extract from his report of August 6, 1918, to the officials of Witt is here given:

> The test of the well indicated a large quantity of water available. A yield of 70 gallons a minute was secured when lowering the water level in the well about 8 feet to a depth of about 14 feet below the ground surface. (The well was 6 inches in diameter, and equipped with a No. 20 Cook screen, 6 feet long.) With a greater area of openings in screen or greater lowering of water level a greater yield would be secured. The ground water level was lowered but a little at a distance of 20 feet from the well.

Special features of Witt system. The final plan at Witt was to construct a circular concrete pump house, 22 feet in diameter, built over two 10-inch wells spaced 18 feet center to center, the pump house being set 10 feet in the ground in order to reduce the lift of the centrifugal pumps. There will really be only about 6 feet of lift for the pumps under present conditions, due to the level of the water in the ground. Another feature of interest is the reinforced concrete water tank, built on the highest point in the city, the tank being 20 feet in diameter and 100 feet in height, the upper 30 feet having 70,000 gallons storage capacity. Two pumping units have been installed, driven by electric motors either of which has sufficient capacity to take care of normal requirements. The author believes it would have been a better plan to have installed possibly one electric motor and one automobile-type gasoline engine as an auxiliary source, each connected to a separate centrifugal pump.

The total cost of the supply system, including wells, pumping station complete with equipment, 8-inch cast iron pipe line 3000 feet long to city limits, and the 70,000 gallon reinforced concrete water tank, was less than $25,000 or about one-fifth the estimated cost of an impounded supply. The distribution system was let as a separate contract in 1919, and cost approximately $10,000 per mile, including valves and hydrants, the total cost of the distribution system being about $70,000 for the 7 miles. It is thus seen that the entire cost of both the supply and distribution systems was only about 75 per cent of the estimated cost of an impounded supply alone.

Value of rational method. Careful examination of the location of known shallow-ground wells with reference to area of watershed will demonstrate the proposition stated by Hubbard and Kiersted that "the yield of the ground water is dependent upon the character and extent of the catchment area and depth of the saturated water bearing material." A most interesting illustration of this is found at Bloomington, Illinois, where the supply is secured from shallow-ground wells. Here the watershed area is only a few square miles at most, while the depth and area of the saturated water-bearing material is necessarily somewhat limited. Year after year desperate efforts have been made there to secure more water from this saturated water-bearing material, and yet the proposition that "no more water can be continuously taken out of the ground than goes into it" has never been fully recognized in the study of the situation, unless possibly within the last months.

Reference is made again to Hubbard and Kiersted; "Shallow-ground water supplies are usually developed from sand and gravel deposits in the valleys of creeks and rivers." In this connection, what are the limits of the deposit at Bloomington? Does it continue down the valley to a point where the catchment area and the depth of deposit are sufficient to supply a future city of 100,000 people? What is the character of the gravel further down the valley? These are important factors, and could be definitely determined at very small expense.

Recently there was witnessed an effort by a city of 5,000 population to secure a shallow ground-water supply from wells located on a catchment area of only about one square mile. Twelve or fifteen wells were put down on one 40-acre tract, and pumping water in one well lowered the water in all the others. This was hardly a rational method of water supply development.

In another city a test was made on a shallow well, driven into about 11 feet of coarse gravel and the supply was pronounced a failure, when as a matter of fact there was a continuous deposit of sand up and down the valley, and available records of the State Geological Survey showed that there was a deposit of 90 feet of gravel within a quarter of a mile of the well tested, with about 50 square miles of catchment area above it.

These are only a few cases which point to the necessity of careful study and intelligent application of the fundamental propositions which govern the development of shallow-ground water supplies.

Goodell, in his book "Water Works for Small Cities and Towns," has also given valuable information on this rational method in the following language:

> The amount of water that may be obtained from deep and shallow wells is so often over-estimated that it is necessary to call attention to the fact that the quantity available depends on the *same* conditions as the amount of surface water, that is, the extent of the catchment area, the rainfall, the proportion of the rainfall entering the ground and the capacity of the basin to hold ground water.

It will of course be borne in mind that where a deep or artesian well is to be developed, a careful geological examination will be necessary.

Turneaure and Russell in "Public Water Supplies" refer to collecting areas for ground-water as follows:

> Deposits of porous material in old lake and river beds often furnish very good collecting-areas for ground-water, and many of the shallower ground-water supplies are from such sources. These deposits are usually covered by other and less pervious strata, and indeed often consist of a series of strata alternately of a pervious and nonpervious nature. This is particularly true of the lacustrine deposits in the basins of the Western mountain region. Old river-channels filled with debris of a porous character give rise to veritable ground-water streams. These may be located some distance from the modern streams, or may at places coincide with or underlie them, forming porous, gravelly beds.
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> Examples of such ground-water streams are very numerous. Leipsic, Germany, is supplied from such a stream about 2 miles in width, 40 feet thick, and having a fall of about 6 feet per mile. The covering stratum is 6 feet thick and the velocity of flow is estimated at about 8 feet per day. Pueblo, Colorado, is supplied with water from a gravel-bed 66,000 squre feet in cross-section with an average depth of 14 feet and a length of 25 miles. Deposits of sand and gravel in the drift are often of considerable extent, and furnish many ground-water supplies, but such deposits are apt to be very irregular in character and uncertain in extent. They occur as accumulations in former stream-beds and also in the form of thin, irregular strata, sometimes of considerable extent, lying for the most part in valleys and covered with more or less clay.

It occurs to the author that we too often fail to make our examination sufficiently broad to learn the true location and character of the collecting-area from which we might secure well supplies.

It is a matter of record in this state as it is also in many others, that we have sand and gravel deposits scattered over a greater portion of the area, that they follow in a general way the old original valleys, sometimes conforming to the outlines of the present valleys; and it is the belief of the author that a careful application of the principles above outlined will enable many of our cities and towns to develop water supplies from such gravel deposits in an economical manner.

Conclusions. In conclusion it is desired to direct attention to the following propositions.

1. With a saturated water-bearing material located on a catchment area of proper extent a shallow-ground water supply will ordinarily be developed at far less expense than an impounded supply.
2. The radius of investigation for shallow-ground water supplies should be increased so that it shall include not only the city limits but extend for a distance of five or possibly even ten miles, beyond the city limits, depending on local conditions, and the availability of an impounded supply.
3. The quality of water secured from one test well in a valley may be entirely different from that in another well in the same general region, due to deposits in the original valley produced by the action of currents. Intersecting creeks and branches will very often show a marked influence on the character and quality of the saturated water-bearing material and the water contained therein.
4. The quantity of water available from a saturated water-bearing material should be determined for various cities as fully as has been done in the case of Pueblo, Colorado, and comprehensive studies of this character should be made a matter of public record in order that the fullest use may be made of them by other towns and cities.

The rational method of water supply development herein discussed does not present any new theories, but does contemplate the application of known engineering principles along such broad, comprehensive lines as judgment and experience may dictate.